JPL MARS OBSERVER IN-FLIGHT ANOMALY INVESTIGATION

(with emphasis on attitude control aspects)

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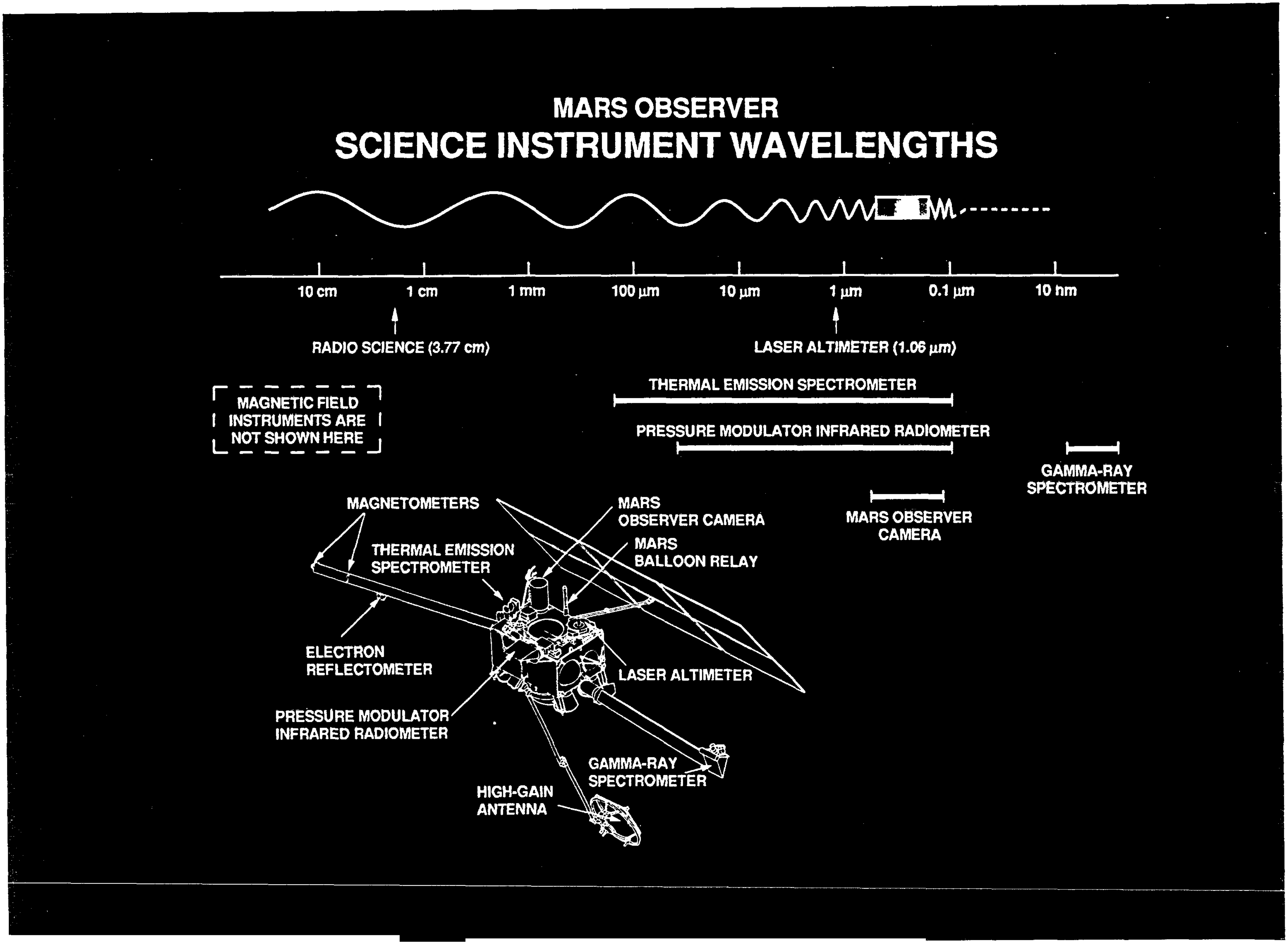
MISSION OBJECTIVES

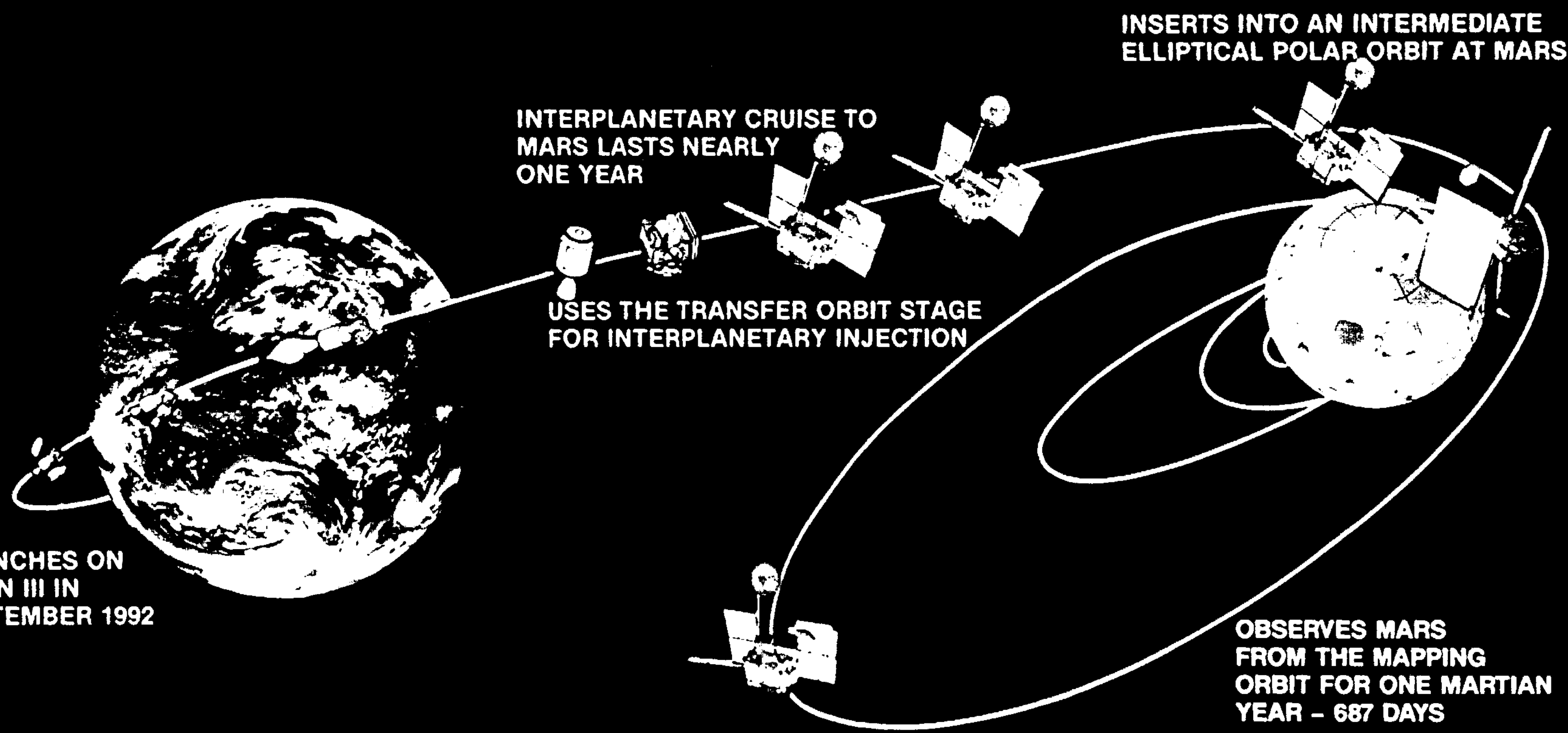
ACQUIRE HIGH-QUALITY GLOBAL OBSERVATIONS OF MARS DURING ONE MARTIAN YEAR TO:

- ADDRESS QUESTIONS ABOUT THE SURFACE, ATMOSPHERE, SOLAR WIND INTERACTION, INTERIOR, GEOLOGIC EVOLUTION, AND CLIMATIC HISTORY OF MARS
- PROVIDE A BASIS FOR BETTER UNDERSTANDING THE EVOLUTIONARY HISTORY OF EARTH THROUGH COMPARATIVE STUDIES WITH MARS AND VENUS
- PROVIDE A GREATLY IMPROVED PERSPECTIVE FOR PLANNING FUTURE MISS1ONS TO MARS



MARS OBSERVER
SCIENCE INSTRUMENT WAVELENGTHS
10 cm
1 cm
1 mm
100 μm
10 μm
1 μm
0.1 μm
10 hm
RADIO SCIENCE (3.77 cm)
LASER ALTIMETER (1.06 μm)
MAGNETIC FIELD INSTRUMENTS ARE NOT SHOWN HERE
THERMAL EMISSION SPECTROMETER
PRESSURE MODULATOR INFRARED RADIOMETER
GAMMA-RAY SPECTROMETER
MARS OBSERVER CAMERA
MAGNETOMETERS
THERMAL EMISSION SPECTROMETER
MARS OBSERVER CAMERA
MARS BALLOON RELAY
ELECTRON REFLECTOMETER
LASER ALTIMETER
PRESSURE MODULATOR INFRARED RADIOMETER
GAMMA-RAY SPECTROMETER
HIGH-GAIN ANTENNA

MARS OBSERVER
MISSION OUTLINE



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BACKGROUND

Launched on September 25, 1992, the Mars Observer spacecraft was to conduct a global survey of the Martian surface and atmosphere.

On August 21, 1993, Mars Observer was executing a sequence to pressurize the propulsion tanks in preparation for Mars Orbit Insertion three days later. As part of that sequence, the transmitter was turned off, and no signal has been detected since.

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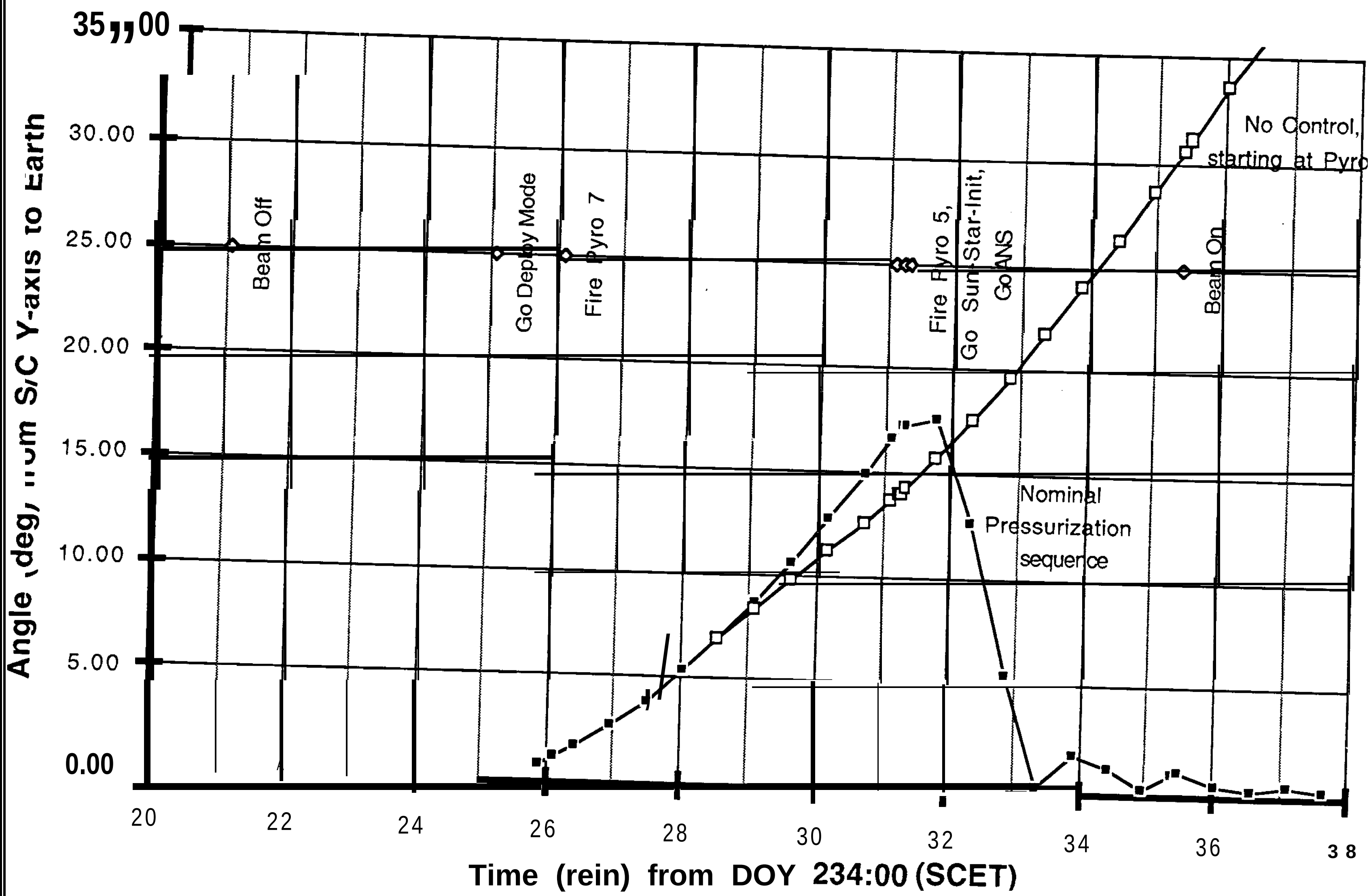
HGA Offset from Earthline During Pressurization



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MOST CREDIBLE CAUSES *

- Loss of downlink or destruction of the spacecraft due to a breach of the Propulsion Subsystem caused by one of the following three mechanisms:
  - -- Propellant reaction in the pressurant lines (Hypothesis Cl A), or
  - -- Pressure regulator failure due to contamination (Hypothesis C2), or
  - -- Ejection of a NSI squib/initiator from the pyro valve (Hypothesis C4)
- Electrical power loss due to a massive short in the Power Subsystem (Hypothesis S2)
- Loss of the spacecraft computational function (both spacecraft computers prevented from controlling the spacecraft) in a way that could not be corrected by ground commands (Hypothesis C5)
- Loss of both transmitters due to failure or latch-up of an electronic part (Hypothesis Cl 6)

* Not prioritized

ATTITUDE CONTROL AND DYNAMICS

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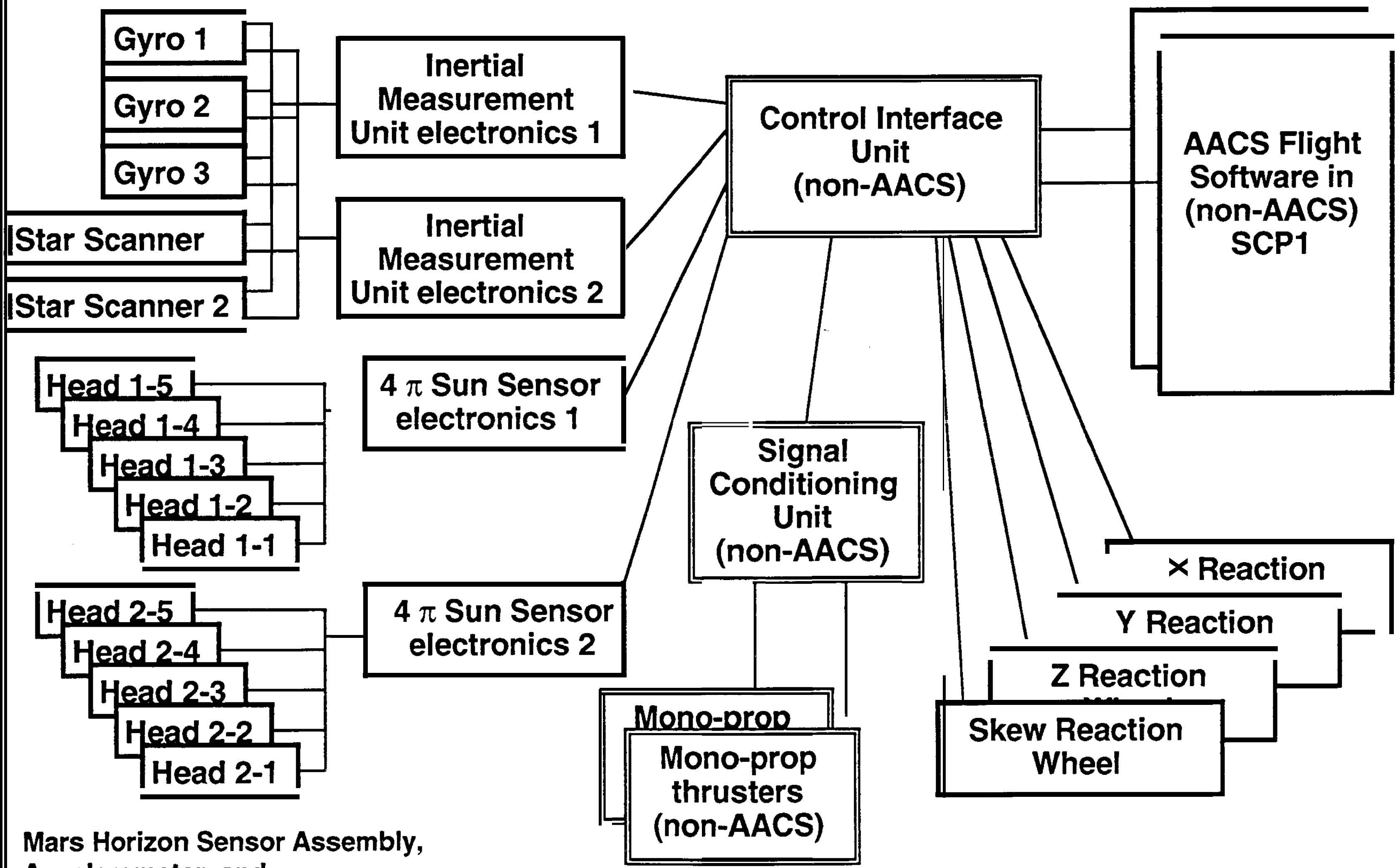
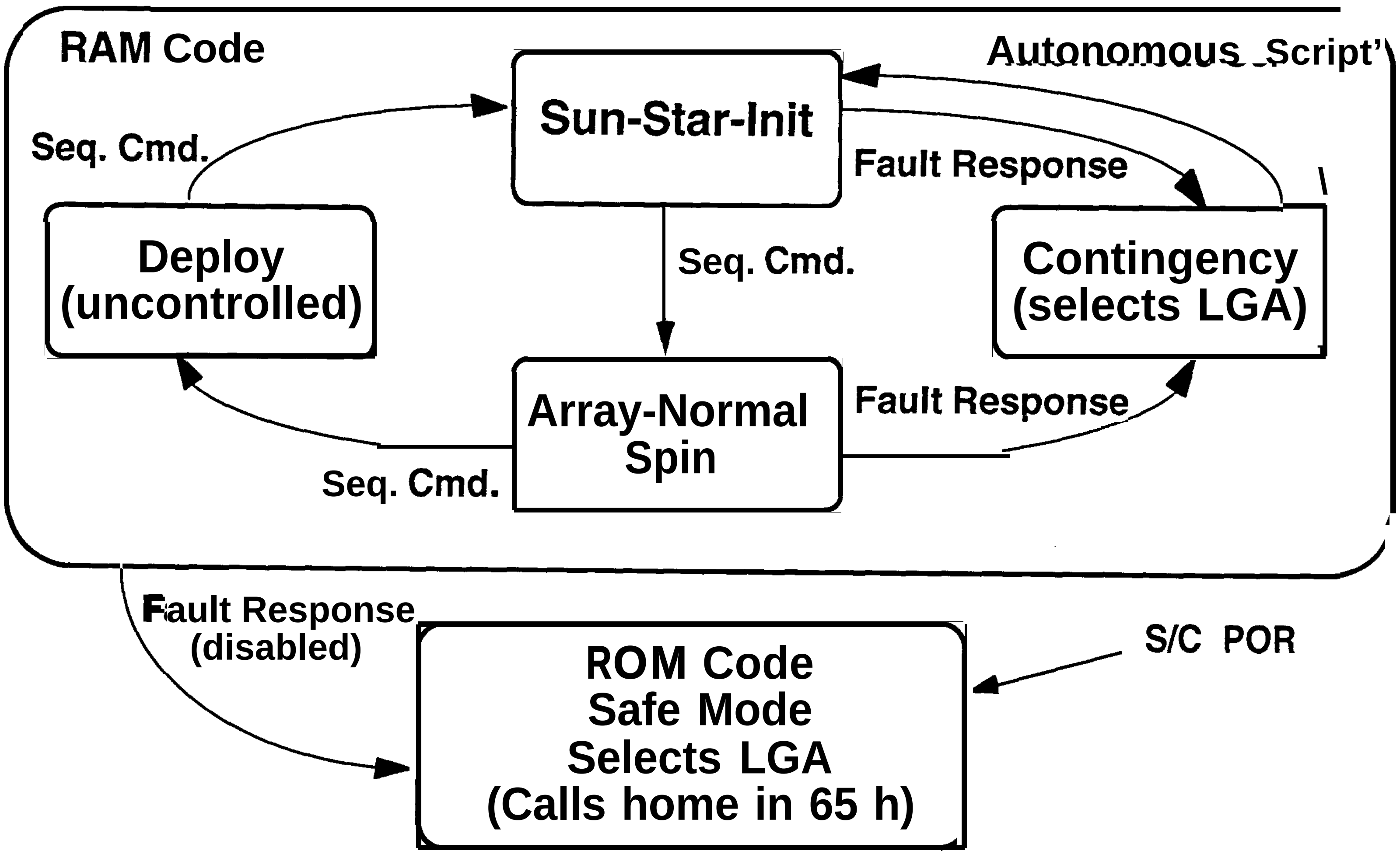
AACS BLOCK DIAGRAM (Cruise)



Mars Horizon Sensor Assembly,
Accelerometer, and
Main Engine Control not shown

SELECTED AACS MODES



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CONTROL OVERVIEW

- **ATTITUDE DETERMINATION**
  - -- Gyro-based attitude propagation; three 2-axis inertial-grade dry-tuned gyros
  - -- Star scanner-based attitude updates; one star at a time when rotating at about 1 rev/100 min
  - -- "4π" steradian Sun sensor for attitude initialization and fault protection
- **ATTITUDE CONTROL**
  - -- Torque 3 of 4 reaction wheels in a 3-orthogonal plus l-skew configuration
  - -- Skew wheel spun during pyro events, can only spin ail 4 wheels in “deploy” (no contingency) mode
  - -- Autonomous momentum unloading
    - - Uses monopropellant thrusters; independent of bipropellant system
    - Disabled when multiple axes exhibit high rates
  - -- No thruster-only attitude control mode
- **FAULT PROTECTION**
  - -- Sun ephemeris vs. measured sun monitor provides functional attitude determination fault protection
  - -- No functional-level fault protection for attitude control errors

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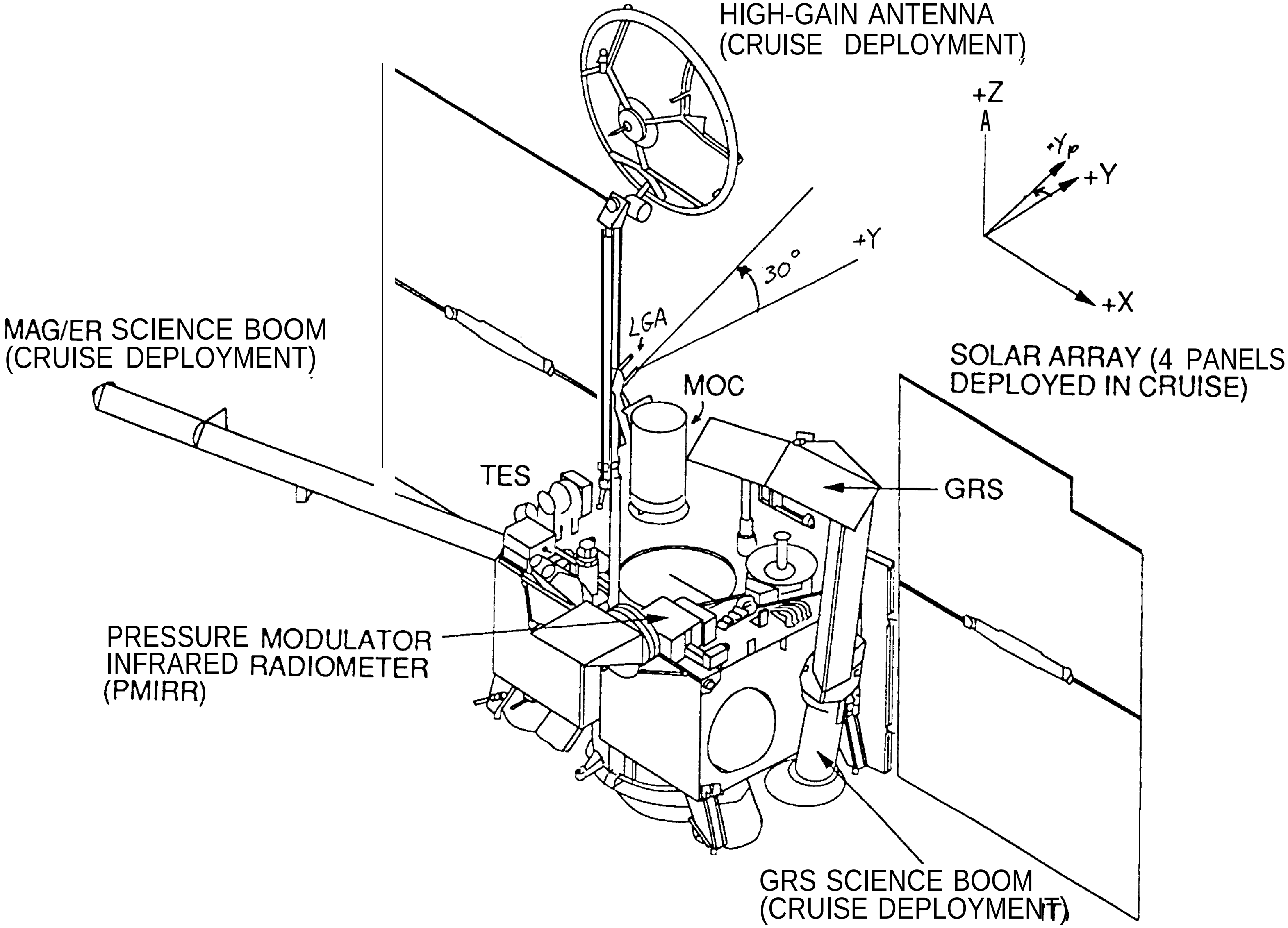
DYNAMICS OVERVIEW

- HGA*, SOLAR ARRAY (SA) NORMAL BOTH APPROXIMATELY PARELLEL TO +Y
- LGA** 30° FROM +Y AXIS TOWARD +Z
- PRINCIPAL AXES:
  - Maximum: (+Y_p) 14° from +Y axis toward -X
  - Intermediate: 24° from +X axis, in the +Y, -Z octant
  - Minimum: 20° from +Z axis, mostly toward +X
- DYNAMICS IMPLICATIONS:
  - After damping, spin will be about an axis close to Y
  - Final uncontrolled dynamical state includes 14° of wobble for HGA and SA normal about maximum principal axis
  - Final uncontrolled dynamical state includes 35° of wobble for LGA about maximum principal axis
  - Uncontrolled spin about X axis is not stable

* HGA - High Gain Antenna

** LGA - Low Gain Antenna

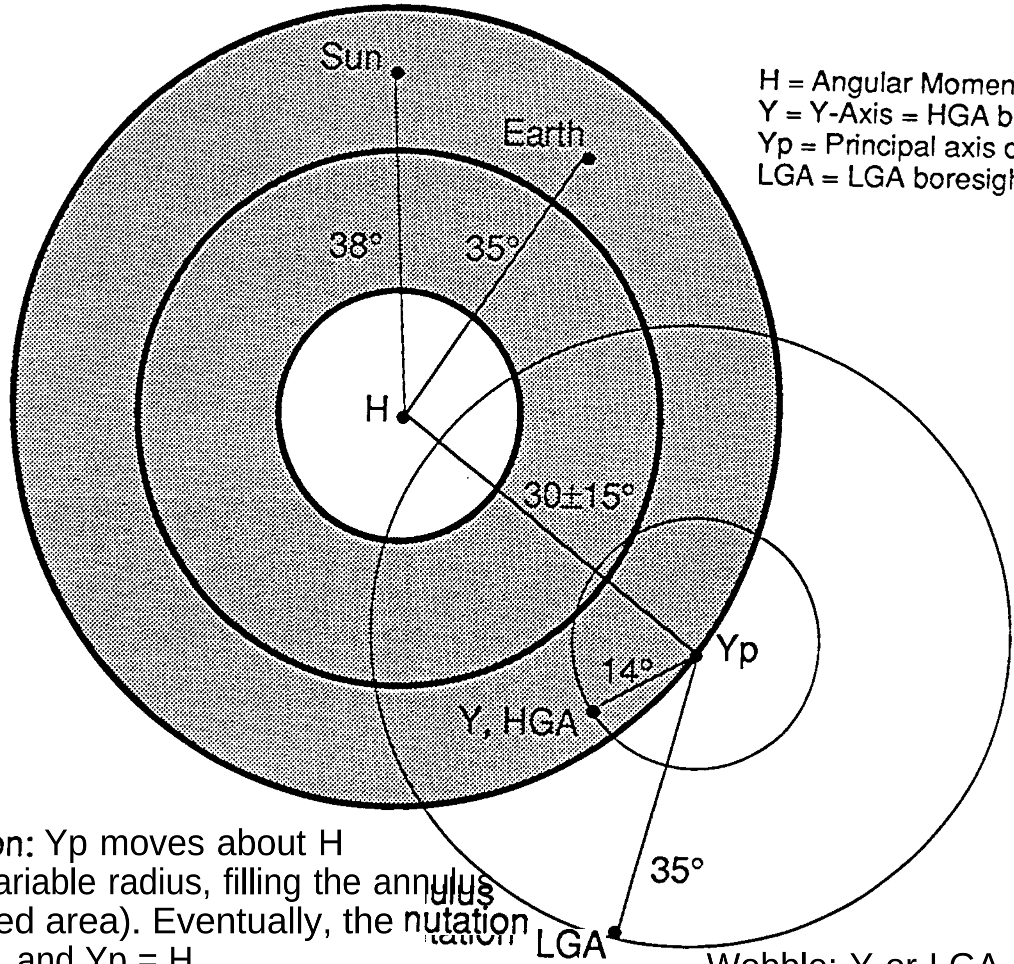


Spacecraft Cruise Configuration

UNCONTROLLED ATTITUDE DYNAMICS
(Relevant to Hypotheses C5 and S2)

- **NUTATION DAMPING**
  - -- Dominated by propellant slosh effects
  - -- Large uncertainty in time constant
  - -- Best time constant estimate: 1 year at 0.20/see; 1 week at 1 0°/sec
- **ANGULAR MOMENTUM**
  - -- Initial direction known 35° from sun-line
  - -- Behavior following nutation damping tractable:
    - - In absence of orbital motion: solar torques precess angular momentum vector about sun-line. Rate = 50 days/rev when H = 9 nms
    - - In presence of orbital motion: center of precession circle displaced about 5° from sun-line. Rate is still 50 days/rev.

NUTATION AND WOBBLE WHEN UNCONTROLLED



H = Angular Momentum Vector
Y = Y-Axis = HGA boresight
Yp = Principal axis of Maximum inertia
LGA = LGA boresight

Nutation: Yp moves about H at a variable radius, filling the annulus (Shaded area). Eventually, the nutation damps, and Yp = H.

Wobble: Y or LGA moves about Yp at a constant radius, never damps.

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CATEGORY A
FAILURE HYPOTHESES

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HYPOTHESIS CIA
Reaction in Lines

Scenario: Temperature gradients and slow diffusion through two series check valves allow ≤2 g of NTO to condense upstream of Pyro valve-5. When PV-5 is opened, some of this NTO is forced into the MMH line and reacts abruptly with the MMH. Peak pressures cause the line to bulge and develop a longitudinal crack. The helium pressurant vents out over 30-60 minutes, followed by the ullage He in the MMH tank and -500 kg of MMH. The gas release causes the spacecraft to spin up to ~10 degrees per second which might preclude detecting the downlink and run down the batteries. For other assumptions, the spacecraft might regain attitude control and/or a downlink might be detected.

Arguments in Favor:

(1) Tests show that transport past check valves will occur

(2) NTO <u>will</u> react with MMH

(3) Analysis and tests show that reaction can cause significant pressure pulse (1 observed in 13 tests)

(4) Causally related to sequence

Arguments Against:

(1) 2 g of NTO requires double check-valve failure; non-failure case yields <0.5 g

(2) Tests produced no significant pressure rise with< 2 g of NTO

(3) Downlink might have been detected in significant subset of cases (attitude stabilizes or HGA sweeps past Earth)

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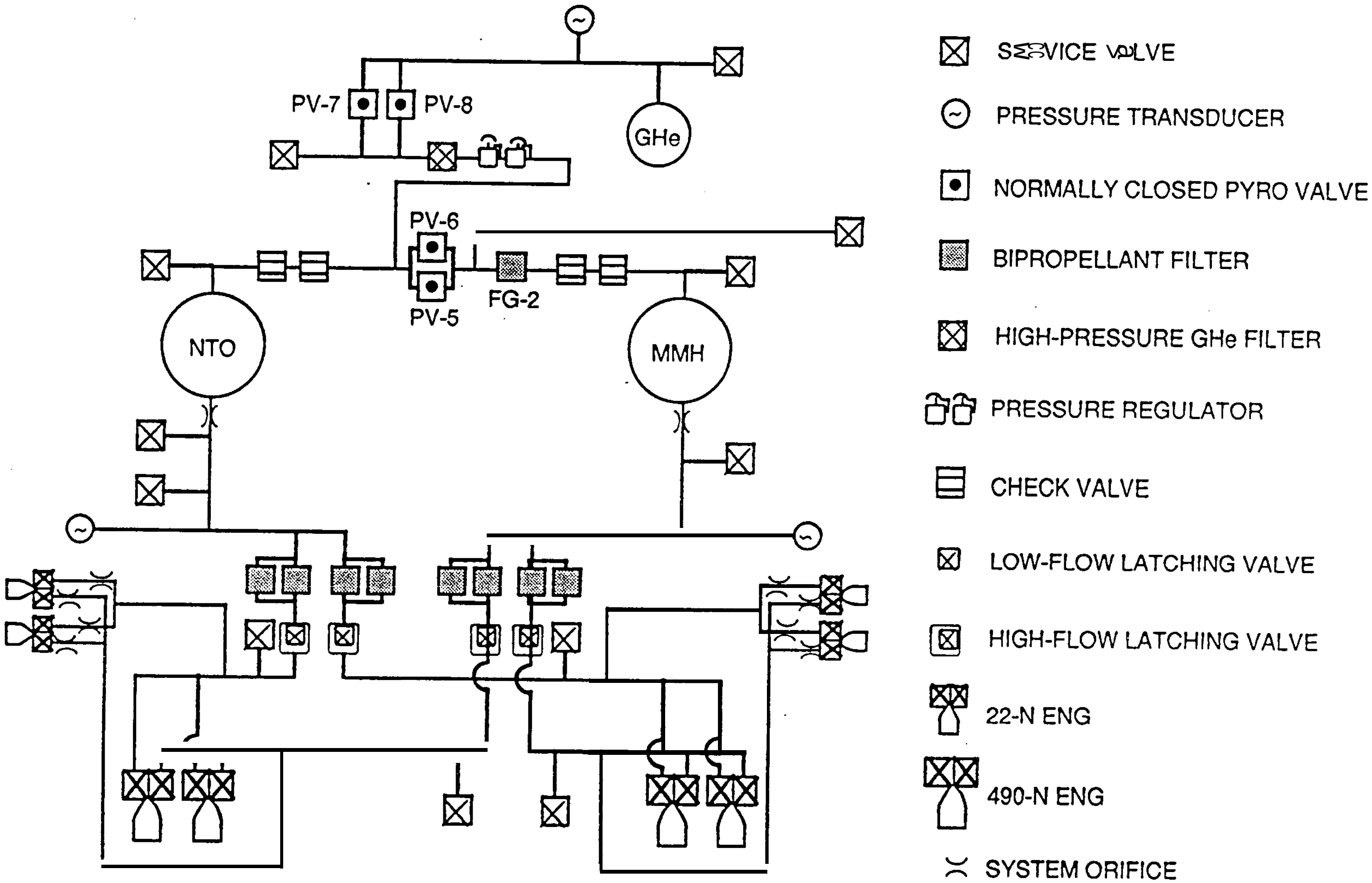

Bipropellant Elements

RRS/DEB 21
Draft 1-25-94

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HYPOTHESIS CIA
Dynamics and Control Summary

- LINE LEAK RELEASES HELIUM UNDER THERMAL BLANKETS
  - -- May burst through blankets giving unrecoverable spin rates
  - -- May exhaust through vents on -Z side of S/C giving X and Y torques
- ASYMMETRIC EXHAUST THROUGH VENTS CAN PRODUCE A WIDE RANGE OF SPIN RATES AND NUTATION ANGLES
  - -- Large thrust asymmetry
    - - quick spin-up, exceed 7.40/s before RPA-On is complete
    - - RPAs not turned on until 10 hours later
    - - battery depletion quite possible before downlink
  - -- Smaller thrust asymmetry
    - - rates exceed 7.40/s after RPA-On is complete
    - - contingency mode entered, LGA chosen and RPA on
    - - good chance of detecting carrier before battery depletion
  - -- Small thrust asymmetry
    - rates kept below 7.40/s at all times
    - - no quick Contingency Mode entry, but RPA on, Autonomous recovery within 2 hours, bringing HGA to Earth-Point
    - - Should detect carrier and reserve telemetry

CIA SIMULATION WITH LARGE THRUST ASYMMEMETRY

Plot from VTL

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CIA SIMULATION WITH SMALL THRUST ASYMMEMETRY

Plot from VTL

HYPOTHESIS C2
Regulator Fails Open

Scenario: The series-redundant regulator has some contamination in the vicinity of the 0.005-inch diameter sensing ports. NTO vapor diffuses past the check valves and reacts with contaminants causing a gummy material that blocks the sensing ports. Pyro valve-7 (high-pressure) is opened to pressurize the NTO tank. The regulator ports become blocked and gas flow continues until the NTO tank bursts 30 to 200 seconds later. Tank burst releases -6x1 05 Joules of energy. The spacecraft experiences immediate critical physical damage.

Arguments in Favor:

(1) Vapor leakage was demonstrated in tests

(2) Some "clean" check valves used for ground tests were contaminated

(3) Shuttle (similar regulator) had a stuck-open failure

(4) Tank would burst well before downlink turned on

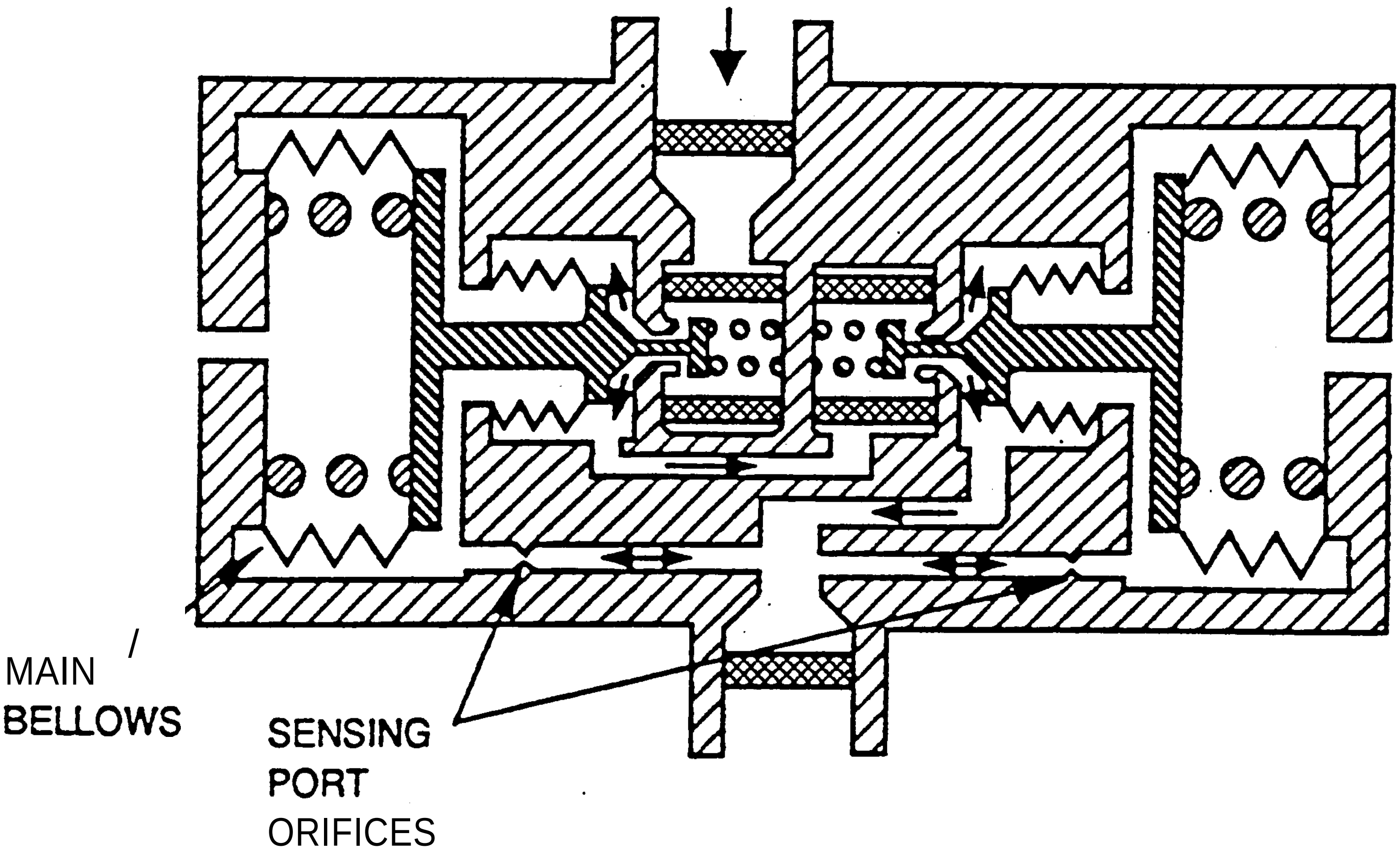
(5) Causally related to sequence

Arguments Against:

(1) Long-term exposure to NTO vapor alone is not a problem on Shuttle

(2) No direct evidence of regulator contamination

(3) Both sensing ports must be blocked



Regulator Schematic

HYPOTHESIS C4
NSI Impacts Tank

Scenario: Pyro valve-5 was fired during the planned pressurization sequence. The inboard (not electrically fired) 15-gram NASA Standard Initiator (NSI) is expelled from the titanium pyro valve body by the high internal pressure pulse at 200 meters per second and strikes the MMH tank. The tank bursts and breaks into fragments and releases $\approx 10^5$ Joules of energy. The spacecraft suffers immediate critical physical damage.

Arguments in Favor:

(1) ESA experienced an initiator expulsion on 3 of 3 Cluster S/C ground tests and 1 of 2 bomb tests

(2) Examination of test-fired MO valves shows thread erosion and chemical attack

(3) Analysis shows thread design to be marginal

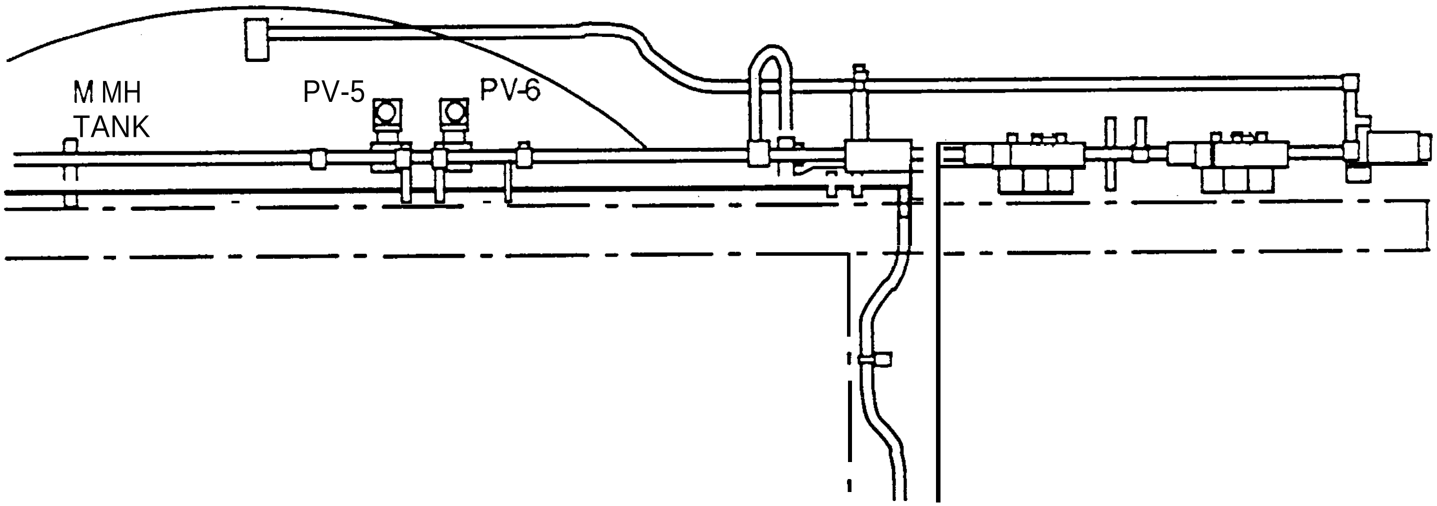
(4) Causally related to sequence

Arguments Against:

(1) ESA initiators were not NSIS -- gave 10-15% higher pressures and faster rise time (but met NSI specification)

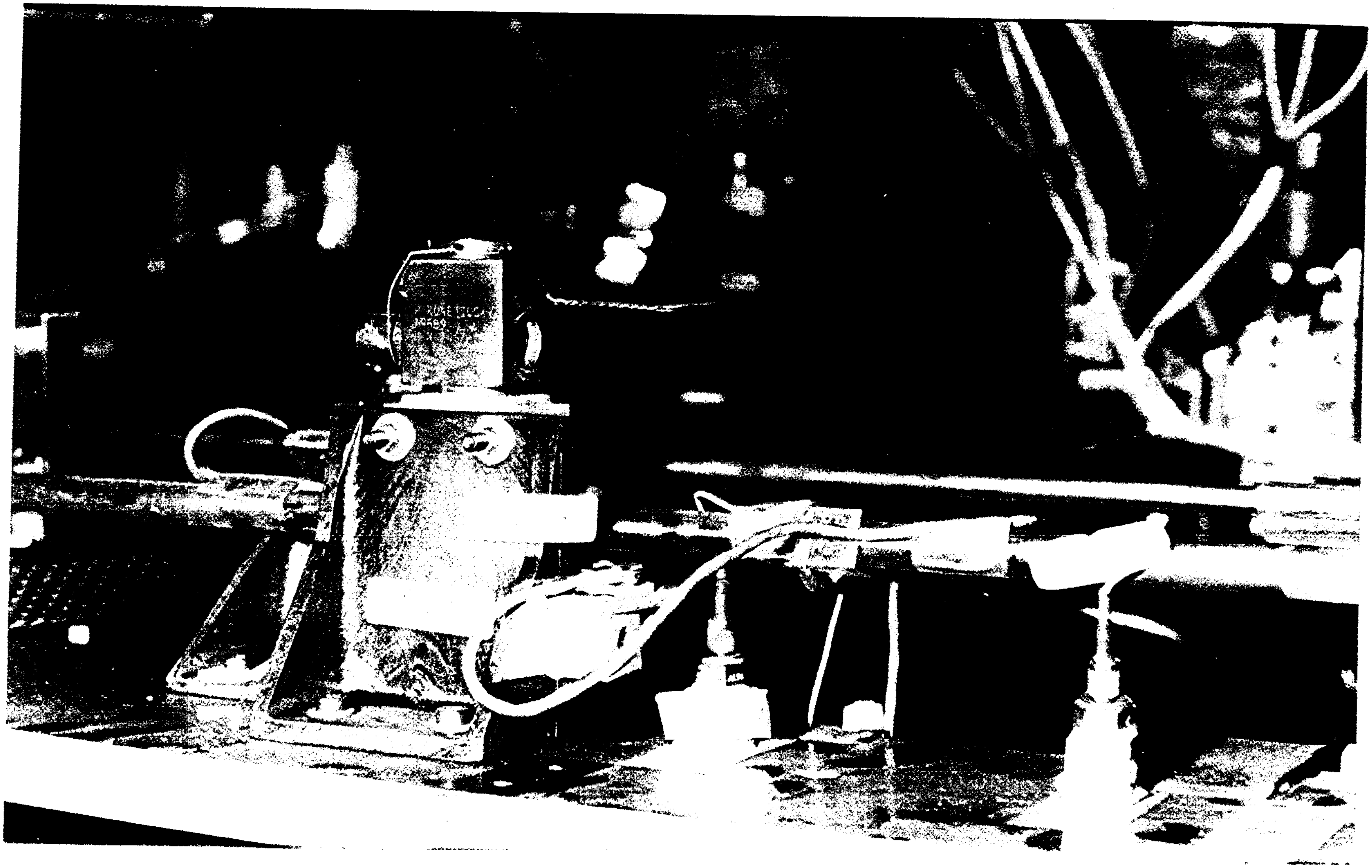
(2) No identical titanium pyro valves with one sympathetically fired NSI are known to have expelled a NSI (O out of 5 known firings)

(3) Only the electrically fired ESA initiators were expelled (outboard on MO)



Relation of Pyro Valves to MMH Tank

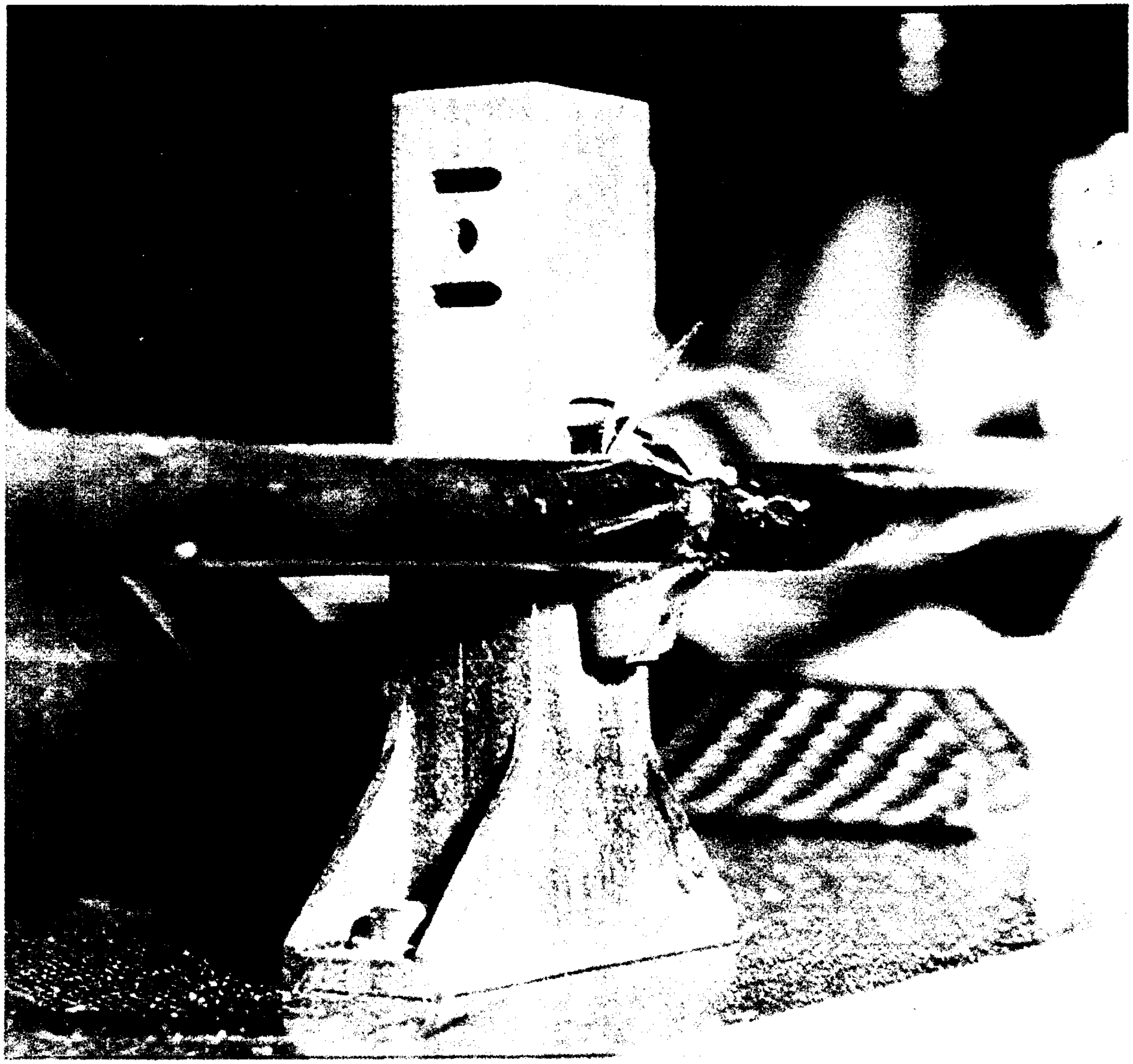
ESA CLUSTER PROGRAM: PYRO VALVE FAILURE



FIRST FIRING TEST (PV5.0)

CFRP FACE SHEET UNDER VALVE BRACKET WAS CRACKED

ESA CLUSTER PROGRAM: PYRO VALVE FAILURE

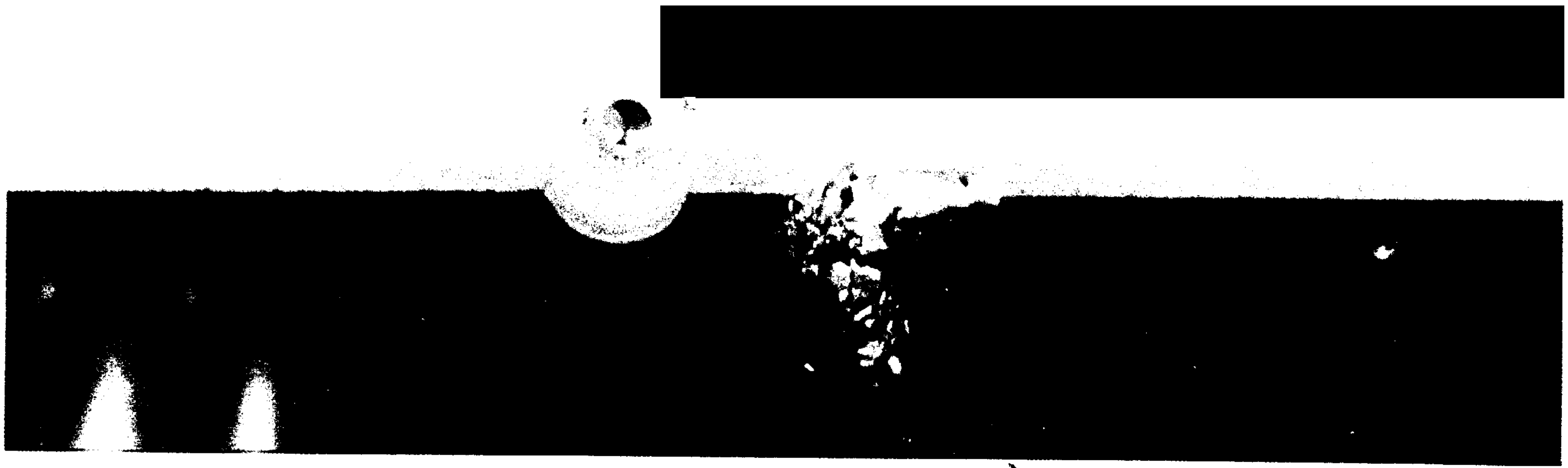


FIRST FIRING TEST (PV5.0)

DAMAGE ON PIPE-SUPPORT-BRACKETS (MADE OF FIBRE-REINFORCED PLASTIC) ABOUT 10 INCHES AWAY FROM THE VALVE

ESA CLUSTER PROGRAM: PYRO VALVE FAILURE

IMPACT DIRECTION



IMPACT DIRECTION

IMPACT POINT OF THE EJECTED INITIATOR (TEST PV5) ON THE EDGE OF 2 SOLAR PANELS (ABOUT 12 mm THICK HONEYCOMB PANEL WITH CARBON FIBRE FACE SHEETS AND FOAMED EDGES) (PHOTOS ARE NOT TO THE SAME SCALE)

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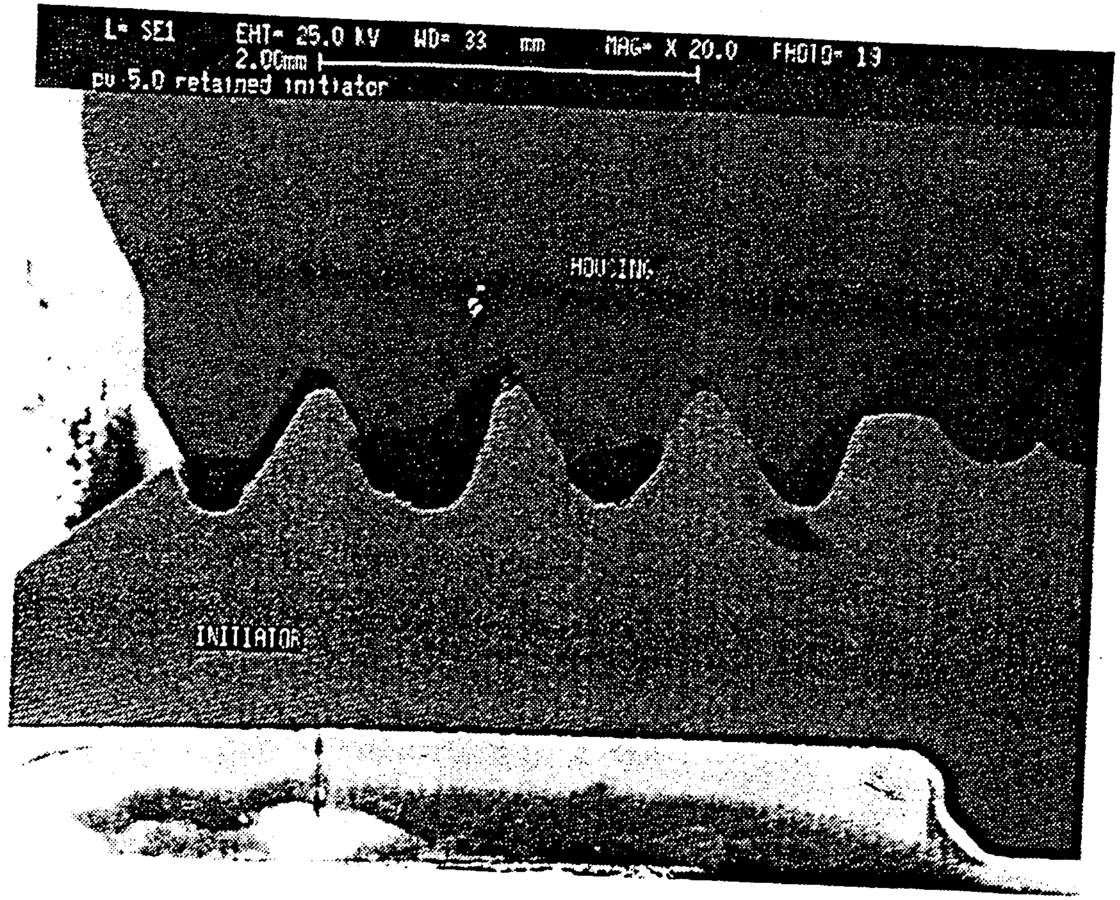
EXAMPLE OF THREAD DAMAGE IN ESA TESTS



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HYPOTHESIS S2
Primary Power Failure

Scenario: The design of the power subsystem allows a single high-side short to chassis in selected parts of the power system to fail the spacecraft. In many places, a thin electrical insulator (6 roils) is the only protection. Workmanship problems, such as burrs, solder balls, debris, tolerance buildup, over-torquing, and improper assembly, could create vulnerable areas. Thermal cycling works the critical areas. After -400 thermal cycles of -15“C, a small thermal change from turning off the RPA (~4°C) causes a short to form. Spacecraft power bus voltage drops and the spacecraft stops functioning.

Arguments in Favor:

(1) Similar failures have occurred in flight (NOAA-1 had a power failure within 1 hour of the MO failure. Mariner II)

(2) Disassembly of spare power system showed poor workmanship (improperly installed isolation bushings, excessive electrically conductive thermal adhesive, and contamination)

(3) Tests show that initial shorts will evolve into permanent, hard shorts (6 out of 9 trials)

Argument Against:

(1) Temperature cycle was small giving a weak tie to pressurization sequence (“straw”).

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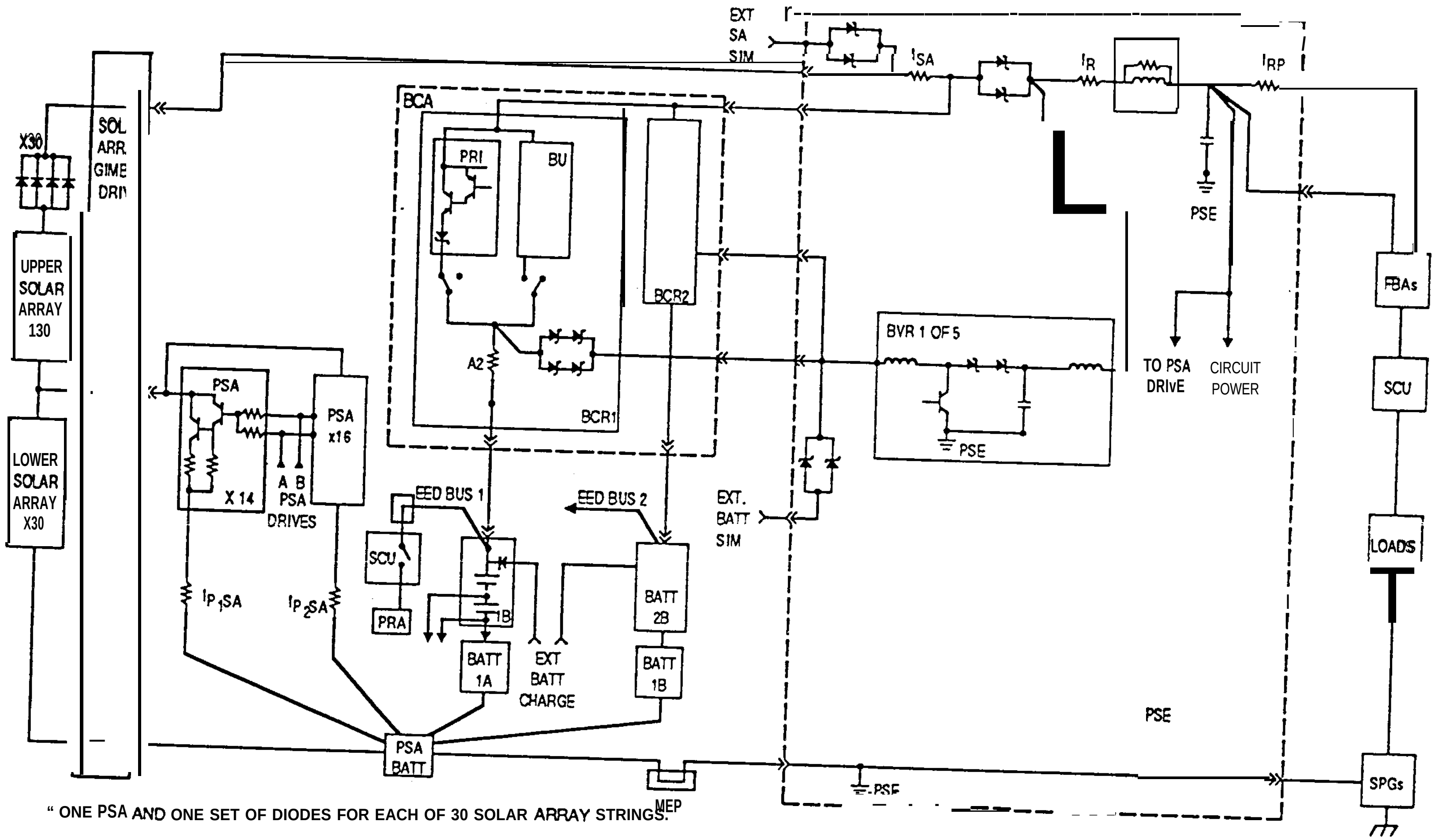

Unfused Power Schematic

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HYPOTHESIS C5
CIU Indeterminacies

Scenario: Firing of Pyro valve-7 or -5 causes a high return current through the chassis (frame) of the spacecraft. The return current loops couple with another circuit which latches up one of several electronic parts. The part failure precludes the spacecraft computer from controlling the spacecraft. The spacecraft transmitter does not come on, the s/c tumbles, and the batteries run down after -22 hours.

Arguments in Favor:

(1) A similar part latch-up happened on Magellan

(2) Pyre-firing chassis currents from 5 to 17 A measured in 8 of 8 recent ground pyro shock tests (6 at about 5A, 1 at 12 A and 1 at 17 A)

(3) High voltages can be induced (2 A can give 31 volts for some circumstances)

(4) Parts latch-up in lab with 30 volt spike

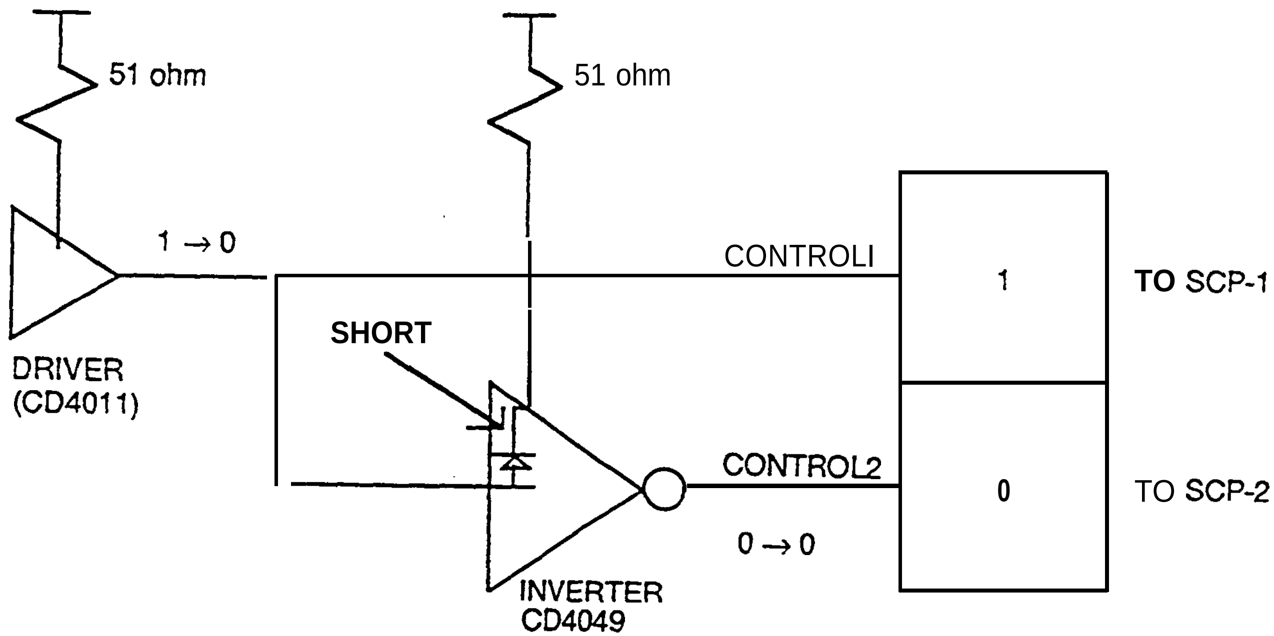
(5) Causally tied to sequence

Arguments Against:

(1) Requires one of several critical parts in a particular circuit to fail (There are hundreds of CD4000 parts on the spacecraft and there were 30 previous pyro firings.)

(2) After the battery runs down, the spacecraft could receive power, POR, clear latch-up, and restabilize -- but it never did

1. [f latch-up occurs, the top protection diode of the inverter is shorted to 5 V.
2. V_{CC} drops to 5 V.
3. The output is now at 5 V (indeterminant—interpreted as “O” by control 2).
4. Pulls output of driver to 5 V (indeterminant—interpreted as “O” by control 1).
5. Therefore, neither SCP-1 nor SCP-2 is active.



SCP In Control

HYPOTHESIS C5
Dynamics and Control Summary

- UNCONTROLLED ATTITUDE DYNAMICS UNDERSTOOD
  - -- Angular momentum vector magnitude and direction known
  - -- RWAS will spin down under friction giving predictable nutation level
  - -- Wobble of solar array normal about principal axis is 14°
  - -- Long nutation damping time constant at these rates; ~ 1 year
- ABOVE ALLOWS POWER BALANCE DETERMINATION WITH CONCLUSION THAT SOLAR INSOLATION IS INSUFFICIENT; BATTERY DEPLETION IN ~ 22 hours
- UNCONTROLLED MOTION WILL BRING PANELS BACK INTO SUN FOLLOWING BATTERY DEPLETION, ALLOWING S/C POR - WHICH CLEARS THE FAILURE
- RWA TORQUING WILL BEGIN BEFORE IRU SPIN-UP IS COMPLETE USING (likely saturated) IRU OUTPUT PREMATURELY
  - -- High torques (drawing high current)
  - -- Often brings down power bus and often turns solar panels away from sun
- EXPECT SUCCESSFUL RECOVERY IN SOME FRACTION OF TRIES; AT LEAST ONE CHANCE PER HOUR

HYPOTHESIS C16
RPA Control Failure

Scenario: The circuit that controls RPA 2 beam-on (active transmitter) fails high at any time after August 2nd (can also be caused by Hypothesis C5 pyro current -- induced latch-up). The cathode heater turned off during pressurization sequence. The heater is turned on again but RPA 2 beam cannot be turned on due to internal RPA logic which requires a low-to-high signal transition to turn on beam. RPA 1 cannot be turned on either because of SCU interlock circuit (to prevent both transmitters from being on simultaneously). Can also occur if RPA 1 beam-on fails high during pressurization sequence.

Arguments in Favor:

(1) Scenario modeling and logic is not uncertain

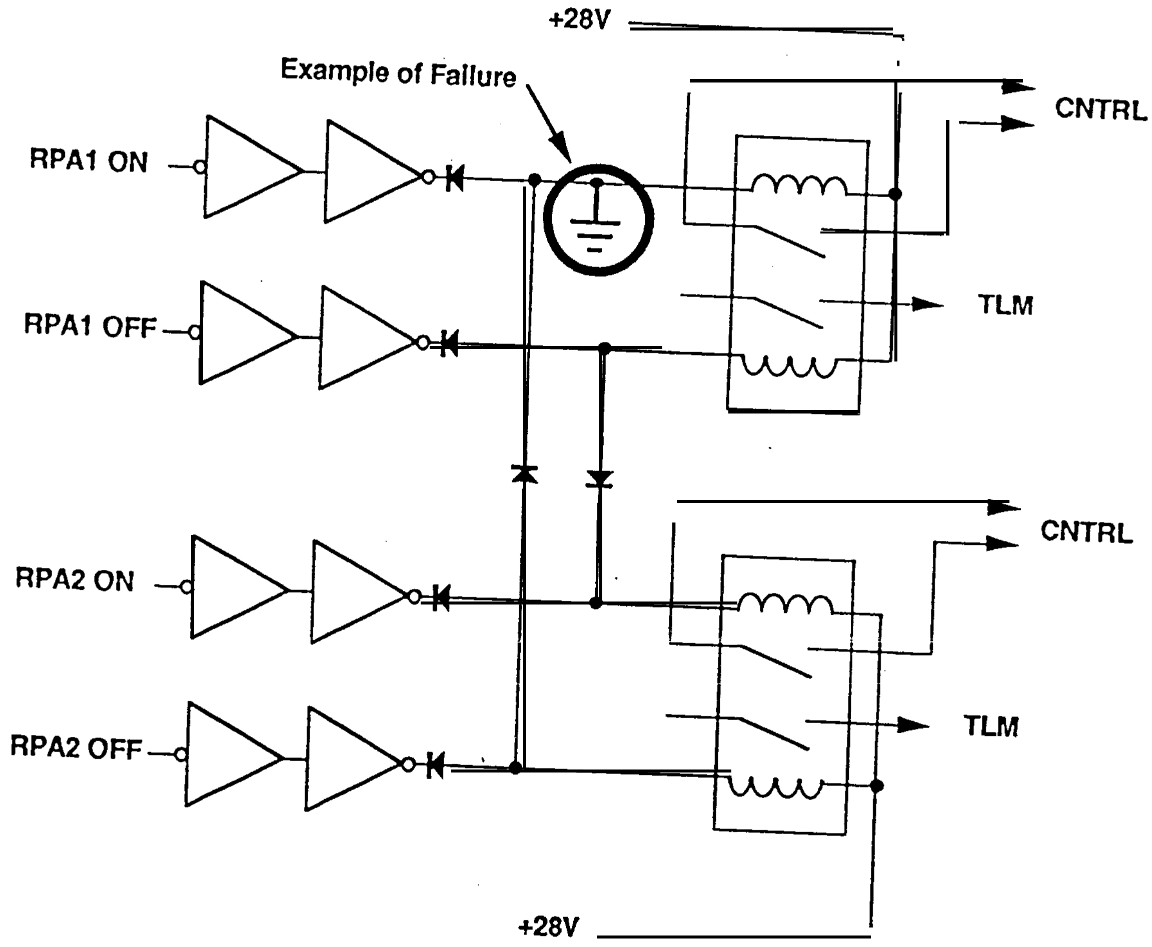
(2) Failure could happen in one of several parts - could be triggered by pyro current

(3) Causally tied to sequence

Argument Against:

(1) Requires one of several critical parts in a particular circuit to fail

Comment: In this scenario, the spacecraft is alive and well in Mars orbit. The MBR experiment can resolve this scenario. A positive signal detection would mean this hypothesis is the single Probable Cause. A negative result is an argument against. Results will not be definitive until May 1994. If a positive detection, there may be a way to clear the latched-up part by intentionally depleting the battery and forcing a POR.



SCU Interlock for RPA: Functional Schematic

RRS/DEB 39
Draft 1-25-94

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SUMMARY AND CONCLUSIONS

- SIX CATEGORY A POTENTIAL CAUSES HAVE BEEN IDENTIFIED AND DESCRIBED
- THE ATTITUDE CONTROL SYSTEM BEHAVIOR IS COMPLEX AND INTERESTING
- RECOMMENDATIONS HAVE BEEN MADE IN THE JPL REPORT TO PREVENT A RECURRENCE
- JPL STUDYING MISSION OPTIONS TO CAPTURE MARS OBSERVER SCIENCE OBJECTIVES
  - -- May require more than one launch
  - -- Spare hardware is available for reuse